Target motion variability and on-line positioning accuracy during external-beam radiation therapy of prostate cancer with an endorectal balloon device

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Abstract: Purpose:: To prospectively define the setup error and the interfraction prostate localization accuracy of the planning target volume (PTV) in the presence of an endorectal balloon (ERB) device. Patients and Methods:: Weekly portal images (PIs) of 15 patients undergoing external-beam radiotherapy were analyzed. Displacements of the isocenter and the center of the ERB were measured. The setup and target motion variability were assessed with regard to the position variability of the ERB. Results:: The setup error was random and target motion variability was largest in the craniocaudal direction. The mean displacement of the isocenter was 2.1 mm (± 1.2 mm SD [standard deviation]), 2.4 mm (± 2.2 mm SD), and 3.8 mm (± 4.0 mm SD) in the left-right, craniocaudal, and anteroposterior directions, respectively (p = 0.1). The mean displacement of the ERB was 2.0 mm (± 1.4 mm SD), 4.1 mm (± 2.0 mm SD), and 3.8 mm (± 3.3 mm SD; p = 0.03). Setup margin and internal margin contributed equally to the PTV margin. Cumulative placement insecurity of the field and the ERB together was 4.0 mm (± 2.1 mm SD) laterally, 6.4 mm (± 2.5 mm SD) craniocaudally, and 7.7 mm (± 7.0 mm SD) anteroposteriorly. The 95% CIs (confidence intervals) were 2.9-5.2 mm, 5.1-7.8 mm, and 3.8-11.5 mm. In 35% of cases, the estimation of the dorsal margin exceeded 1 cm. Conclusion:: Margin estimate dorsally may exceed 1 cm and on-line position verification with an ERB cannot be recommended for dose escalation > 70 Gy

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Target Motion Variability and On-Line Positioning Accuracy during External-Beam Radiation Therapy of Prostate Cancer with an Endorectal Balloon Device

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Purpose: To prospectively define the setup error and the interfraction prostate localization accuracy of the planning target volume (PTV) in the presence of an endorectal balloon (ERB) device.
Patients and Methods: Weekly portal images (PIs) of 15 patients undergoing external-beam radiotherapy were analyzed. Displacements of the isocenter and the center of the ERB were measured. The setup and target motion variability were assessed with regard to the position variability of the ERB.
Results: The setup error was random and target motion variability was largest in the craniocaudal direction. The mean displacement of the isocenter was 2.1 mm (± 1.2 mm SD [standard deviation]), 2.4 mm (± 2.2 mm SD), and 3.8 mm (± 4.0 mm SD) in the left-right, craniocaudal, and anteroposterior directions, respectively (p = 0.1). The mean displacement of the ERB was 2.0 mm (± 1.4 mm SD), 4.1 mm (± 2.0 mm SD), and 3.8 mm (± 3.3 mm SD; p = 0.03). Setup margin and internal margin contributed equally to the PTV margin. Cumulative placement insecurity of the field and the ERB together was 4.0 mm (± 2.1 mm SD) laterally, 6.4 mm (± 2.5 mm SD) craniocaudally, and 7.7 mm (± 7.0 mm SD) anteroposteriorly. The 95% CIs (confidence intervals) were 2.9–5.2 mm, 5.1–7.8 mm, and 3.8–11.5 mm. In 35% of cases, the estimation of the dorsal margin exceeded 1 cm.
Conclusion: Margin estimate dorsally may exceed 1 cm and on-line position verification with an ERB cannot be recommended for dose escalation > 70 Gy.

Key Words: Prostate cancer · Endorectal balloon · PTV · Position accuracy · Intensity modulation

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Organmobilität und Lokalisationsbestimmung der Prostata unter Einsatz eines endorektalen Ballons bei der Radiotherapie des Prostatakarzinoms

Ziel: Analyse des Positionierungsfehlers und der Lokalisationsgenauigkeit der Prostata zwischen den Bestrahlungen unter der Verwendung eines endorektalen Ballons (ERB) zwecks Positionierungshilfe.
Patienten und Methodik: Die sequentiellen Einstellungsaufnahmen von 15 Patienten, die in kurativer Absicht eine externe Radiotherapie erhielten, wurden analysiert. Die Positionierungsvariabilität des ERB wurde unter Berücksichtigung der Lagevariabilität des Set-up und des Zielvolumens gemessen.
Ergebnisse: Der Einstellungsfehler (systemischer Fehler) zeigte keine Prädispositionen in x-, y- oder z-Richtung. Die Bewegungsvariabilität in kraniokaudaler Richtung war am größten. Die Lagevariabilität des Feldzentrums betrug 2,1 mm (± 1,2 mm), 2,4 mm (± 2,2 mm) und 3,8 mm (± 4,0 mm) in seitlicher, kraniokaudaler und anteroposteriorer Richtung (p = 0,1). Der ERB zeigte eine Lagevariabilität von 2 mm (± 1,4 mm), 4,1 mm (± 2,0 mm) und 3,8 mm (± 3,3 mm) seitlich, kraniokaudal und anteroposterior (p = 0,03). Die Positionsvariabilität des Feldzentrums in Bezug auf die Lokalisation des ERB war vernachlässigbar. Zur kumulativen Zielunsicherheit trugen der systemische und der spezifische Fehler gleichermaßen bei. Die durchschnittliche Lageunsicherheit des Feldes und des Ballons gemeinsam betrug 4,0 mm (± 2,1 mm) lateral, 6,4 mm (± 2,5 mm) kraniokaudal und 7,7 mm (± 7,0 mm) anteroposterior. Die 95%-Konfidenzintervalle betrugen 2.9–5.2 mm, 5.1–7.8 mm, und 3.8–11.5 mm. Der geschätzte Sicherheitsabstand in dorsaler Richtung lag in 35% der Fälle bei > 1 cm.
Schlussfolgerung: Um einen Sicherheitsrand von < 1 cm gegen dorsal zu erzielen, reicht ein ERB allein nicht aus. Für Therapien mit Dosen > 70 Gy empfehlen sich zusätzliche Positionierungs- und Positionsverifikationssysteme, um den dorsalen Sicherheitsabstand klein halten zu können.

Schlüsselwörter: Prostatakarzinom · Endorektaler Ballon · Positionsgenauigkeit · PTV · Intensitätsmodulation

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Introduction

On-line position verification of the prostate is a prerequisite for high-dose external-beam radiotherapy (EBRT) to the prostate. Dose escalation improves biochemical relapse-free survival and conformal radiotherapy (CRT) decreases treatment-related morbidity [5, 6, 9, 11–13, 22, 25, 26, 35]. CRT and multileaf collimators (MLCs) reduce the volume of normal tissue included in the planning target volume (PTV) by up to 40% compared to conventional radiotherapy (RT) and thus decrease the normal-tissue complication probability (NTCP) [10]. Reduced dose delivered to non-cancer tissue, however, is defined by the setup margin surrounding the cancer tissue in the clinical target volume (CTV). The PTV margin as defined by ICRU (Report No. 62) consists of two components, the internal margin (IM) reflecting anatomic position variability and the setup margin, defined by the daily positioning and machine geometry variability [16]. The IM accounts for changes in shape, size, and motion of the CTV, while the setup margin accounts for errors in positioning. One of the major problems is the interfraction motion of the prostate affected by rectal and bladder filling and contractions of the pelvic floor [7, 18, 28, 30, 33, 34].

Interfraction motion can be reduced with positioning devices such as casts or leg holders, fixation devices such as endorectal balloons (ERBs) or spacers [3, 14, 15, 31], by treating only patients with a full bladder (500 cm^3 of fluids), and the use of laxatives to minimize pelvic organ filling and motion of the prostate [4, 27, 29]. Direct visualization before treatment with ultrasound or pretreatment session computed tomography (CT) scans has been evaluated [17]. Gold fiducial markers implanted in the prostate may also be used to assess interfraction mobility and allow on-line prostate position verification [19]. Implantation of markers, however, is an invasive procedure and carries a small but definitive risk of complications such as septicemia, hematuria, hemospermia, and rectal bleeding [1, 33].

In the present study, we prospectively evaluated the ability of an ERB device to reduce the posterior PTV margin and whether an ERB by itself would be suitable for dose escalation treatment without additional prostate positioning techniques.

Patients and Methods

15 patients with non-metastatic node-negative adenocarcinoma of the prostate undergoing conformal EBRT with curative intent were investigated. The patients' average age was 70.7 years (range: 65–78 years). The mean prostate-specific antigen (PSA) at presentation was 25.4 ng/l (± 25.6 ng/l SD [standard deviation]; range: 0.4–106 ng/l). Five patients each presented with stage T1c, T2, and T3 disease. The median Gleason Score was 7 (range: 5–10). All patients had CT-based treatment planning and were treated as described previously [3]. An ERB was placed in the rectum and inflated with 60 cm^3 of air, followed by RT planning (Pinnacle TM, Philips Laboratories GmbH, Düsseldorf, Germany) target delineation. Patients were treated using a four-field box technique with MLCs on a 6-MV linear accelerator (Varian 600c or 6EX, Varian Associates, Palo Alto, CA, USA). After 50 Gy, the PTV margin was reduced. 70 Gy in 2 Gy per day over 7 weeks were applied.

Portal images (PIs) were acquired using an electronic portal imaging device (EPID). The first image was acquired before delivering the first fraction and compared to the digitally reconstructed radiograph (DRR) of the corresponding field. PIs were obtained weekly [2].

PIs were transferred with DICOM (Digital Imaging and Communication in Medicine) via a verifying system (Multi-Access, Impact Medical system, Palo Alto, CA, USA) for our analysis. To depict the center of the radiation field, a grid setup was used. The ERB outline and the center of the balloon were defined. Measurements were taken from the isocenter and a fixed bony landmark to assess setup variations. Measurements from the center of the ERB to the same bony landmarks were used to determine the interfraction target mobility. The measurements recorded from the DRR served as baseline and any deviation recorded in any of the subsequent PIs was measured.

Statistical Analysis

SDs were calculated according to the formula $S^2 = \Sigma(X–M)/N$, where X is the value of the score, M is the mean, and N is the number of scores. The 95% confidence intervals (CIs) were computed with Z = (t 0.95) × SEM (standard error of the mean). The comparison between the mean setup and target motion variation was assessed with Student's paired t-test. Setup variations, as well as organ movement in the course of RT, were calculated using a repeated measures analysis of variance test.

Results

Position of the Isocenter in Relation to the Symphysis Pubis

The mean distance between the symphysis pubis (SP) and the center of the field in the lateral direction was 3.4 mm (± 1.1 mm SD), and the median 3.7 mm (range: 1.6–6.0 mm) with a 95% CI of 2.8–4.0 mm. In the craniocaudal direction, the average distance between the upper border of the SP and the center of the field was 2.9 mm (± 0.66 mm SD), and the median 12.2 mm (range: 2.7–23.1 mm) with a 95% CI of 9.2–16.6 mm. In the anteroposterior direction, the center of the field averaged 56.3 mm (± 8.0 mm SD), with a median value of 54.0 mm (range: 44.3–70.6 mm) and a 95% CI of 51.8–60.7 mm. Results are summarized in Table 1.

Position of the Center of the ERB in Relation to the Symphysis Pubis

As for the ERB, the mean distance between the SP and the center of the ERB in lateral direction was 2.8 mm (± 1.5 mm SD), and the median 2.9 mm (range: 0.4–5.4 mm) with a 95% CI of 2.0–3.6 mm. Craniocaudally, the mean distance between center of the ERB and the upper border of the SP was 12.0 mm

(± 6.5 mm SD), with a median of 12.6 mm (range: 3.2–22.9 mm) and a 95% CI of 8.5–15.6 mm. Finally, in the anteroposterior direction, the ERB was 98.1 mm dorsal of the SP (± 6.3 SD), with a median of 98.7 mm (range: 86.1–107.7 mm) and a 95% CI of 94.6–101.6 mm. Results are summarized in Table 2.

Assessment of Setup Variations

Mean displacement of the center of the field from its baseline position in the lateral direction was 2.1 mm (± 1.2 mm SD), with a median value of 2.1 mm (range: 0.2–4.8 mm). In the craniocaudal direction, the displacement was 2.4 mm (± 2.2 mm SD), with a median of 1.5 mm (range: 0.5–7.8 mm). In the anteroposterior direction, displacement of the field center was 3.8 mm (± 4.0 mm SD), with a median of 2.5 mm (range: 0.1–16.3 mm). There were no significant differences between the displacement of the field center in x, y, or z ($p = 0.1$).

Assessment of Target Mobility Variations

The mean lateral displacement of the center of the balloon was 2.0 mm (± 1.4 mm SD), with a median of 1.6 mm (range: 0.4–4.8 mm). In the craniocaudal direction, mean displacement was 4.1 mm (± 2.0 mm SD), with a median of 3.9 mm (range: 1.6–7.2 mm). Anteroposteriorly, mean displacement was 3.8 mm (± 3.3 mm SD), with a median of 2.9 mm (range: 0.4–11.7 mm). Overall differences were statistically significant ($p = 0.03$), especially the difference between the lateral and the craniocaudal variations ($p = 0.007$). No difference of the displacement variability of the center of the balloon and the center of the ERB were found, and the contributions of the setup margin and the IM to the final PTV margin were comparable (Table 3).

The mean and the SD of the target mobility are shown for the lateral (Figure 1a), craniocaudal (Figure 1b), and anteroposterior (Figure 1c) directions. Variations exceeding 10 mm were recorded in 1.7%, 12.5%, and 17% of measurements in the lateral, craniocaudal, and anteroposterior directions of motion, respectively.

Assessment of PTV Margins

Total combined displacement variability of the field and the ERB laterally was 4.0 mm (± 2.1 mm SD), with a median of 4.1 mm (range: 0.8–6.9 mm) and a 95% CI of 2.9–5.2 mm. In the craniocaudal direction, the displacement was 6.4 mm (± 2.5 mm SD), with a median of 7.0 mm (range: 2.3–9.6 mm) and a 95% CI of 5.1–7.8 mm. In the anteroposterior direction, the mean value was 7.7 mm (± 7.0 mm SD), with a median of 5.5 mm (range: 0.6–28 mm) and a 95% CI of 3.8–11.5 mm (Table 4). PTV margins were 5.2 mm laterally, 7.8 mm craniocaudally, and 11.5 mm anteroposteriorly. The PTV margin in the anteroposterior direction exceeded 10 mm in 35% of incidences.

Discussion

Minimizing RT dose delivered to the rectal wall during curative treatment of prostate cancer is important to avoid unnecessary toxicity [20]. We and others have previously shown, that an ERB reduces prostate mobility and the dose of ionizing radiation delivered to the rectal mucosa [7, 15, 32]. We measured PTV margins in the absence of additional prostate localization techniques except an ERB. We found that internal motion and field setup variability in the presence of an ERB alone results in a suboptimal PTV margin in anteroposterior direction exceeding a positioning accuracy of 1 cm in one third of patients.

Table 1. Distance of the field center to the symphysis pubis (SP). CI: confidence interval; SD: standard deviation.

Tabelle 1. Position der Feldmitte in Bezug zur Symphyse (SP). CI: Konfidenzintervall; SD: Standardabweichung.

SP–field center	Lateral direction	Craniocaudal direction	Anteroposterior direction
Mean (± SD)	3.4 mm (± 1.1 mm)	2.9 mm (± 0.66 mm)	56.3 mm (± 8.0 mm)
Median (range)	3.7 mm (1.6–6.0 mm)	12.2 mm (2.7–23.1 mm)	54.0 mm (44.3–70.6 mm)
95% CI	2.8–4.0 mm	9.2–16.6 mm	51.8–60.7 mm

Table 2. Distance of the center of the endorectal balloon (ERB) to the symphysis pubis (SP). CI: confidence interval; SD: standard deviation.

Tabelle 2. Variabilität der Distanz zwischen Mitte des ERB zur Symphyse (SP). CI: Konfidenzintervall; ERB: endorektaler Ballon; SD: Standardabweichung.

SP–ERB	Lateral direction	Craniocaudal direction	Anteroposterior direction
Mean (± SD)	2.8 mm (± 1.5 mm)	12.0 mm (± 6.5 mm)	98.1 mm (± 6.3 mm)
Median (range)	2.9 mm (0.4–5.4 mm)	12.6 mm (3.2–22.9 mm)	98.7 mm (86.1–107.7 mm)
95% CI	2.0–3.6 mm	8.5–15.6 mm	94.6–101.6 mm

Table 3. Displacement of the center of the field and the center of the endorectal balloon (ERB) in relation to the symphysis pubis. SD: standard deviation.

Tabelle 3. Positionsvariabilität der Feldmitte in Bezug zur Mitte des endorektalen Ballons (ERB). SD: Standardabweichung.

Mean displacement (± SD)	Lateral direction	Craniocaudal direction	Anteroposterior direction	p-value
Field	2.1 mm (± 1.2 mm)	2.4 mm (± 2.2 mm)	3.8 mm (± 4.0 mm)	0.1
ERB	2.0 mm (± 1.4 mm)	4.1 mm (± 2.0 mm)	3.8 mm (± 3.3 mm)	0.03
p-value	0.9	0.07	0.9	

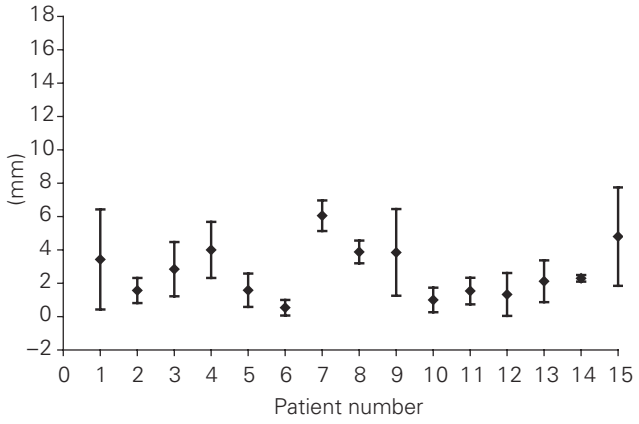

Figure 1a – Abbildung 1a

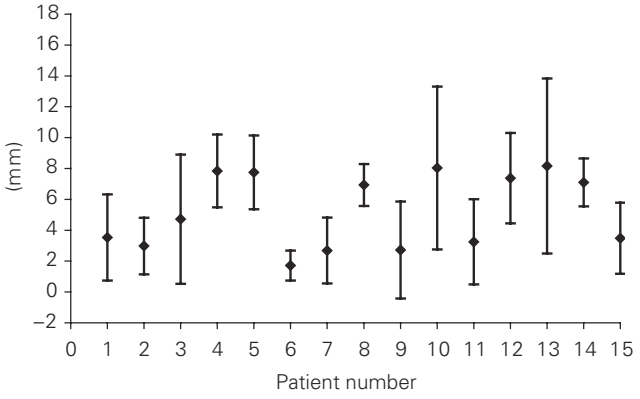

Figure 1b – Abbildung 1b

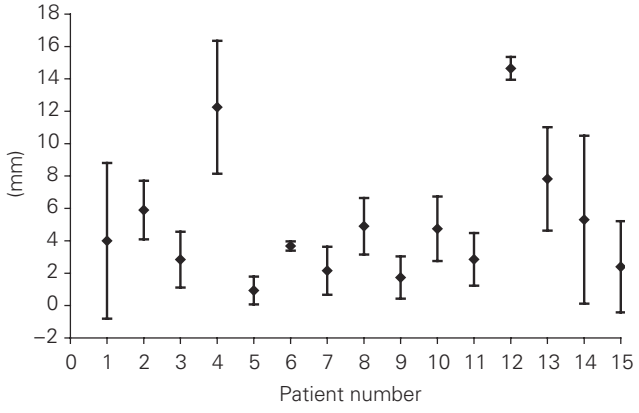

Figure 1c – Abbildung 1c

Figures 1a to 1c. Mean and SD of the endorectal balloon mobility in the lateral (a), craniocaudal (b), and anteroposterior (c) direction for individual patients.

Abbildungen 1a bis 1c. Mobilität des endorektalen Ballons in lateraler (a), kraniokaudaler (b) und anteroposteriorer (c) Richtung (Mittelwert und SD).

We accepted the ERB mobility as a surrogate for prostate mobility in this study based on our previous analysis [7]. We assumed that the position variability of the ERB represents internal target positioning variability and the interfraction mobility. Overall, IM variability was comparable to the setup variability. However, besides the inaccuracy in anteroposterior direction, the ERB seems insufficient for prostate location for the purpose of dose escalation, because the IM in craniocaudal direction exceeds the setup variability, which is consistent with our previous study [3]. The imprecision in craniocaudal direction may be substantial for cases requiring treatment of the seminal vesicles.

Several authors reported on ERB and motion variability and PTV margins. McGary et al. assessed prostate displacement in ten patients with an ERB during the course of intensity-modulated radiation treatment (IMRT) [21]. The prostate displacement in the anteroposterior and the lateral direction was shown to be in the order of ~1 mm. The SD of the craniocaudal displacements was 1.8 mm and comparable to the SD in the present study. In a comparative study by D'Amico et al., the mean displacement of the prostate with an ERB was 1.3 (0–2.2) mm compared to 1.8 (0–9.1) mm ($p = 0.03$) without an ERB, and the ERB reduced prostate motion variability [8]. Maximum displacement was reduced from 4 mm to ≤ 1 mm using a balloon. Wachter et al. found that maximum displacements of posterior prostate border (> 5 mm) were found in eight of ten patients without and in only two of ten patients with an ERB [32].

Table 4. Sum of the displacements of the center of the field and the center of the endorectal balloon (ERB) in relation to the symphysis pubis. CI: confidence interval; SD: standard deviation.

Tabelle 4. Summe der Positionsveränderungen der Feldmitte und der Mitte des endorektalen Ballons in Bezug zur Symphyse. CI: Konfidenzintervall; SD: Standardabweichung.

∑ (field + ERB) displacement	Lateral direction	Craniocaudal direction	Anteroposterior direction
Mean (± SD)	4.0 mm (± 2.1 mm)	6.4 mm (± 2.5 mm)	7.7 mm (± 7.0 mm)
Median (range)	4.1 mm (0.8–6.9 mm)	7.0 mm (2.3–9.6 mm)	5.5 mm (0.6–28 mm)
95% CI	2.9–5.2 mm	5.1–7.8 mm	3.8–11.5 mm

The balloon reduced the posterior rectal wall volume in the high-dose regions without changing exposure of the anterior half of the rectal wall. Van Lin et al. compared patients irradiated using an ERB to patients without an ERB [31]. Patients had gold markers implanted, as well, and an off-line electronic portal imaging correction protocol was used for prostate position verification; the fiducial markers were effective in reducing the systematic prostate displacements, whereas the ERB did not reduce the interfraction prostate motion. Patel et al. evaluated the volumes of the rectal wall and the bladder receiving high-dose RT in respect of presence or absence of an ERB for 3D-conformal RT, IMRT, and helical tomotherapy [23, 24]. An ERB in 3D-CRT reduced the rectal volume by 40%, 42%, and 44% at doses of 60 Gy, 65 Gy, and 70 Gy, respectively. Interestingly, helical tomotherapy resulted in the smallest volume of the rectum irradiated to a high dose when compared to 3D-CRT. Recently, van Lin et al. reported that an ERB used during dose escalation resulted in significant rectal wall sparing potentially reducing late rectal toxicity [31].

Taken together, the PTV margin anteroposteriorly do not seem to be reduced to < 1 cm by the ERB. Thus, the ERB by itself is not sufficient for elimination of interfraction motion of the prostate in respect of the area of the anterior rectal wall exposed to high-dose RT. Additional positioning techniques such as intraprostatic fiducial markers or on-line CT imaging may reduce PTV margins sufficiently for dose escalation.

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References

1. Alasti H, Petric MP, Catton CN, et al. Portal imaging for evaluation of daily on-line setup errors and off-line organ motion during conformal irradiation of carcinoma of the prostate. Int J Radiat Oncol Biol Phys 2001;49:869–84.
2. Bakai A, Paulsen F, Plasswilm L, et al. [Positioning accuracy in conformational prostatic irradiation using portal imaging.] Strahlenther Onkol 2002;178:84–90.
3. Baumert BG, Zagralioglu O, Davis JB, et al. The use of a leg holder immobilisation device in 3D-conformal radiation therapy of prostate cancer. Radiother Oncol 2002;65:47–52.
4. Beard CJ, Kijewski P, Bussiere M, et al. Analysis of prostate and seminal vesicle motion: implications for treatment planning. Int J Radiat Oncol Biol Phys 1996;34:451–8.
5. Beckendorf V, Guerif S, Le Prise E, et al. The GETUG 70 Gy vs. 80 Gy randomized trial for localized prostate cancer: feasibility and acute toxicity. Int J Radiat Oncol Biol Phys 2004;60:1056–65.
6. Cavey ML, Bayouth JE, Colman M, et al. IMRT to escalate the dose to the prostate while treating the pelvic nodes. Strahlenther Onkol 2005; 181:431–41.
7. Ciernik IF, Baumert BG, Egli P, et al. On-line correction of beam portals in the treatment of prostate cancer using an endorectal balloon device. Radiother Oncol 2002;65:39–45.
8. D'Amico AV, Manola J, Loffredo M, et al. A practical method to achieve prostate gland immobilization and target verification for daily treatment. Int J Radiat Oncol Biol Phys 2001;51:1431–6.
9. Dearnaley DP, Hall E, Lawrence D, et al. Phase III pilot study of dose escalation using conformal radiotherapy in prostate cancer: PSA control and side effects. Br J Cancer 2005;92:488–98.
10. Dearnaley DP, Khoo VS, Norman AR, et al. Comparison of radiation side-effects of conformal and conventional radiotherapy in prostate cancer: a randomised trial. Lancet 1999;353:267–72.
11. De Meerleer G, Vakaet L, De Gersem W, et al. Direct segment aperture and weight optimization for intensity-modulated radiotherapy of prostate cancer. Strahlenther Onkol 2004;180:136–43.
12. Galalae RM, Loch T, Riemer B, et al. Health-related quality of life measurement in long-term survivors and outcome following radical radiotherapy for localized prostate cancer. Strahlenther Onkol 2004;180:582–9.
13. Ganswindt U, Paulsen F, Anastasiadis AG, et al. 70 Gy or more: which dose for which prostate cancer? J Cancer Res Clin Oncol 2005;131:407–19.
14. Gerstner N, Wachter S, Dorner D, et al. [Significance of a rectal balloon as internal immobilization device in conformal radiotherapy of prostatic carcinoma.] Strahlenther Onkol 1999;175:232–8.
15. Hille A, Schmidberger H, Tows N, et al. The impact of varying volumes in rectal balloons on rectal dose sparing in conformal radiation therapy of prostate cancer. A prospective three-dimensional analysis. Strahlenther Onkol 2005;181:709–16.
16. ICRU Report 62. Perscribing, recording, and reporting photon beam therapy (Supplement to ICRU Report 50). Bethesda: ICRU, 1999.
17. Kupelian PA, Thakkar VV, Khuntia D, et al. Hypofractionated intensity-modulated radiotherapy (70 Gy at 2.5 Gy per fraction) for localized prostate cancer: long-term outcomes. Int J Radiat Oncol Biol Phys 2005; 63:1463–8.
18. Langen KM, Jones DT. Organ motion and its management. Int J Radiat Oncol Biol Phys 2001;50:265–78.
19. Litzenberg D, Dawson LA, Sandler H, et al. Daily prostate targeting using implanted radiopaque markers. Int J Radiat Oncol Biol Phys 2002; 52:699–703.
20. Mavroidis P, Al-Abany M, Helgason AR, et al. Dose-response relations for anal sphincter regarding fecal leakage and blood or phlegm in stools after radiotherapy for prostate cancer. Radiobiological study of 65 consecutive patients. Strahlenther Onkol 2005;181:293–306.
21. McGary JE, Teh BS, Butler EB, et al. Prostate immobilization using a rectal balloon. J Appl Clin Med Phys 2002;3:6–11.
22. Mock U, Bogner J, Georg D, et al. Comparative treatment planning on localized prostate carcinoma: conformal photon- versus proton-based radiotherapy. Strahlenther Onkol 2005;181:448–55.
23. Patel RR, Orton N, Tome WA, et al. Rectal dose sparing with a balloon catheter and ultrasound localization in conformal radiation therapy for prostate cancer. Radiother Oncol 2003;67:285–94.
24. Patel RR, Tomé WA, Orton N, et al. The use of an endorectal balloon catheter and ultrasound localization in conformal radiation therapy for prostate cancer: a DVH analysis of rectal dose-sparing with 3D-CRT, IMRT, and helical tomotherapy. Int J Radiat Oncol Biol Phys 2002;54: Suppl 1:259.
25. Perez CA, Michalski JM, Purdy JA, et al. Three-dimensional conformal therapy or standard irradiation in localized carcinoma of prostate: preliminary results of a nonrandomized comparison. Int J Radiat Oncol Biol Phys 2000; 47:629–37.
26. Pollack A, Zagars GK, Starkschall G, et al. Prostate cancer radiation dose response: results of the M.D. Anderson phase III randomized trial. Int J Radiat Oncol Biol Phys 2002;53:1097–105.
27. Roeske JC, Forman JD, Mesina CF, et al. Evaluation of changes in the size and location of the prostate, seminal vesicles, bladder, and rectum during a course of external beam radiation therapy. Int J Radiat Oncol Biol Phys 1995;33:1321–9.
28. Stroom JC, Koper PC, Korevaar GA, et al. Internal organ motion in prostate cancer patients treated in prone and supine treatment position. Radiother Oncol 1999;51:237–48.
29. Van Herk M, Bruce A, Kroes AP, et al. Quantification of organ motion during conformal radiotherapy of the prostate by three-dimensional image registration. Int J Radiat Oncol Biol Phys 1995;33:1311–20.
30. Van Lin EN, Hoffmann AL, van Kollenburg P, et al. Rectal wall sparing effect of three different endorectal balloons in 3D conformal and IMRT prostate radiotherapy. Int J Radiat Oncol Biol Phys 2005;63:565–76.

31. Van Lin EN, van der Vight LP, Witjes JA, et al. The effect of an endorectal balloon and off-line correction on the interfraction systematic and random prostate position variations: a comparative study. Int J Radiat Oncol Biol Phys 2005;61:278–88.
32. Wachter S, Gerstner N, Dorner D, et al. The influence of a rectal balloon tube as internal immobilization device on variations of volumes and dose-volume histograms during treatment course of conformal radiotherapy for prostate cancer. Int J Radiat Oncol Biol Phys 2002; 52:91–100.
33. Wu J, Haycocks T, Alasti H, et al. Positioning errors and prostate motion during conformal prostate radiotherapy using on-line isocentre set-up verification and implanted prostate markers. Radiother Oncol 2001; 61:127–33.
34. Zelefsky MJ, Crean D, Mageras GS, et al. Quantification and predictors of prostate position variability in 50 patients evaluated with multiple CT scans during conformal radiotherapy. Radiother Oncol 1999; 50:225–34.
35. Zietman AL, DeSilvio ML, Slater JD, et al. Comparison of conventional-dose vs high-dose conformal radiation therapy in clinically localized adenocarcinoma of the prostate: a randomized controlled trial. JAMA 2005; 294:1233–9.

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